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Evolution of Burn Resuscitation in Operation Iraqi Freedom

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Burns are common in all military conflicts, comprising approximately 10% of all casualties. Of these, nearly 20% are categorized as severe, or involving greater than 20% TBSA, and require significant intravenous resuscitation.[1] A unique set of challenges have emerged during the present conflict associated with global evacuation of burned soldiers, adding a new dimension to the already-complex and often-controversial topic of the burn resuscitation.[2] Critical advances in air evacuation of the war wounded, thorough prewar planning, and sustained burn care education of deployed personnel have proven vital in the optimal care of our injured soldiers.[1,3] During the Vietnam conflict, burned soldiers were evacuated to an Army Hospital in Japan (Camp Zama) and were treated for up to 6 months before they were evacuated to the United States.[4] Since that time, the transfer of the patient to the burn center for definitive care has been expedited by the Army Burn Flight Team's ability to transport the most severely burned patients within the first several days after injury. With the emergence of the U.S. Air Force Critical Care Air Transport Team (CCATT) program in the 1990s, global air evacuation of burn patients became even more rapid, maximizing available U.S. Air Force aircraft for patient evacuation.[5] The doctrine has shifted from aeromedical transport of the stable to aeromedical transport of the stabilized.

In burn patients, evacuation presents a unique problem because it usually takes place while resuscitation in the first 24 to 48 hours after burn injury is ongoing. In addition to the innate complexity involved in global evacuation, war burn patients often exhibit multisystem traumatic injuries further complicating and augmenting resuscitation fluid needs above and beyond standard burn resuscitation formulas.[6] The presence of smoke inhalation injury, occurring in 5% to 15% of patients with severe burns, also increases fluid requirements. In most cases, the critical first days of burn resuscitation of the war wounded lies on the shoulders of physicians and nurses who do not specialize in burn care with priorities focused on stabilization and evacuation to the place of definitive care. Providing guidance and "standardizing" practice based on current available knowledge applied in this setting has been our greatest challenge. In this article, we aim to review the evolution of initial burn care of the war wounded during the current conflict and provide some insight into future directions.

CONSEQUENCES OF UNDER-RESUSCITATION

Severe burn injury results in massive fluid shifts from the intravascular space into the interstitium and intracellular space in burned and nonburned tissues.[7] This fluid shift results in intravascular volume depletion and hemoconcentration with an elevation in the blood hematocrit that usually is observed clinically in the first 24 hours after burn.[8] Delayed or inadequate replacement of intravascular volume results in suboptimal tissue perfusion associated with end-organ failure and death. The goal of fluid resuscitation after severe burn is to replace loss of intravascular volume with intravenous crystalloid to maintain adequate tissue perfusion throughout the 48-hour period of increased capillary leak and relative hypovolemia at the lowest physiologic cost.[9] It is important to consider that patients with severe burns, extensive soft-tissue trauma, inhalation injury, or electrical injury will require the administration of increased amounts of fluid

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to prevent burn shock. In certain patients, burn shock and resuscitation failure will occur despite optimal resuscitation by experienced personnel because of a combination of factors associated with limits in cardiovascular reserve and adverse host responses.[10]

CONSEQUENCES OF OVER-RESUSCITATION

Early in this conflict, fear of under-resuscitation appeared to be the predominant concern in the early management of the burn soldiers throughout theater. Recently, the dangers of exceeding the amount of intravenous resuscitation required to allow for adequate tissue perfusion have been recognized. Pruitt[11] has used the analogy of "pushing the pendulum back" in burn resuscitation to avoid "fluid creep" and the complications of over-resuscitation. We have termed the effects of over-resuscitation as "resuscitation morbidity," a constellation of complications that may include abdominal compartment syndrome (ACS), airway obstruction, extremity compartment syndromes, and pulmonary edema.[12–15] A resuscitation volume greater than 237 ml/kg over the course of 12 hours (or 16 liters during a 12-hour period in a 70-kg man) appears to be the threshold for the development of ACS.[16] ACS results in decreased renal blood flow and subsequent renal failure, intestinal ischemia, respiratory failure, and death if not recognized even and treated early.[17] The treatment of ACS by drain placement and abdominal escharotomy followed by the last resort of a decompressive laparotomy may improve survival but is associated with dramatic increases in morbidity.[13,18–21] The mortality of a decompressive laparotomy for ACS in burned patients is documented to be 60% to 100%.[13,22]

PROBLEMS IDENTIFIED

Prehospital/Precombat Support Hospital Care

Soldiers injured in Iraq are evacuated to medical care on average of 30 to 60 minutes from the time of injury to a combat support hospital (CSH), where subspecialty care can be delivered. This protocol most likely reflects the urban nature of the battlefield, along with strategic placement of forward hospitals. In fact, run times are shorter on average for soldiers in Operation Iraqi Freedom than civilian burn injuries transferred to the U.S. Army Burn Center, Institute of Surgical Research (ISR) in San Antonio from our catchment area in south Texas (approximately 3 hours). In contrast to Iraq, coalition forces engaged in Operation Enduring Freedo) in Afghanistan often require evacuation times exceeding 4 hours before reaching a CSH because of a combination of factors, such as the rural nature of the conflict, the mountainous terrain, and weather conditions, which hamper both air and ground evacuation. Burned soldiers requiring intravenous fluid (IVF) resuscitation pose a logistic problem for medical personnel accompanying them. Carrying adequate quantities of IVF without compromising unit mobility has been continuing challenge for far-forward medics.

Global Evacuation

Rapid global evacuation of burned soldiers to ISR has been a priority during this conflict in an effort to minimize infectious complication and organ failure, which can ensue without definitive treatment (i.e., surgical excision of burn wounds). Currently, a severely burned casualty initially is resuscitated and stabilized at a CSH followed by helicopter transport to a theater hospital, where the patient is prepared for air transport by CCATT to the U.S. military hospital at Landstuhl, Germany. This transport typically occurs within the timeframe of initial resuscitation. At the Landstuhl Regional Medical Center, the patient continues to undergo resuscitation in anticipation of air evacuation to the U.S. Army Burn Center in San Antonio. From Landstuhl Regional Medical Center, the patient may be transported by either the Army's Burn Flight Team or an available CCATT, depending upon the severity of burn injury, number of burn patients, and timing of evacuation flights. Therefore, the burn casualty typically will be cared for by a number of providers at multiple levels in the evacuation chain before arriving at the burn center. Variation in practice during evacuation remains a system-wide issue.

Provider Turnover

In preparation for the war, ISR training teams provided Advanced Burn Life Support and Combat Burn Life Support courses to train more than a thousand military personnel in the United States, Germany, and the Middle East.[3] Although this training is still ongoing, the constant flux of new deployed providers every 4 to 6 months into theater has produced gaps. Thus, some degree of longitudinal practice variation is unavoidable because of constant physician and nurse turnover, each with variable levels of experience and training in burn care. Recognition of this variation in practice over time added yet another element to the challenge of standardizing care in theater.

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SOLUTIONS

Identification of mutilevel challenges, from prehospital care to the global evacuation system early in the conflict, has resulted in the development of various solutions.

Prehospital/Precombat Support Hospital

Field resuscitation guidelines have been developed to reduce unnecessary fluid administration and conserve stocks on hand. For example, guidelines created for hemorrhagic shock use easily accessible clinical endpoints, such as mentation and palpable radial pulse to decrease or stop infusion of IVF.[23] Although a standardized prehospital guideline specific for severe burns (>20% TBSA) has not been developed, medics on the battlefield are instructed to obtain peripheral access and start Ringers' Lactate using these same endpoints. Some military unit medical personnel carry only colloid solutions (ie, hetastarch) in place of standard crystalloid solutions in attempt to reduce the weight of IVF transported while maintaining the ability to replace lost volume in injured soldiers. Because hetastarch is a large-molecular-weight colloid, it may have particular advantages under conditions of increased microvascular permeability seen in burn injuries. In this environment, colloids may be both an excellent solution to the packing constraints imposed by the battlefield as well as effective resuscitation fluid, which spares excess volume infused.[24] This may in turn have implications in preventing intraabdominal hypertension and ACS, although this needs to be better defined in a burn population.

Predeployment training

Efforts to improve knowledge and skill sets of deploying providers with respect to burn care have led to multiple initiatives by the ISR. A day-long course focused on burn management was incorporated as a component of the Extremity War Surgery course offered to all deploying surgeons. Combat support hospital staff members are provided with burn specific training during the predeployment training process. This type of education greatly decreases the amount of anxiety and stress associated with treating a subset of patients generally not managed by non-burn center personnel.

Regular Deployment Rotation

Since March 2005, a burn surgeon from the ISR has been positioned to one of the combat support hospitals deployed in Iraq. This surgeon serves as one of the general surgeons assigned to the CSH and simultaneously serves as the theater consultant for thermal injury and burn surgery. In this capacity, he or she provides input to medical policy, rapid consultation for deployed providers, and operative assistance. With the assistance of the burn surgeon, standard admission and burn wound care order sets were created to allow more uniformity and consistency with respect to treatment throughout theater. Consultation may include assessment using digital imagery, discussion of treatment plans, and assistance with evacuation. Another important part of the consultant's role in theater is to provide education and training for both physician and nursing staff. This education extends beyond the military personnel organic to the hospital, but to the host nation providers as well. The long-term focus of the burn consultant is improvement and enhancement of the burn treatment capabilities within the host nation.

Theaterwide Video Teleconference

In October 2005 regular weekly video-teleconference meetings were established with all the CSHs in both theaters, Landstuhl Army Medical Center, representatives of the aeromedical evacuation community, Brooke Army Medical Center, Walter Reed Army Medical Center, and The Bethesda National Naval Medical Center. This provides the capability to provide real-time feedback for any identified problems. These conferences have proven to be invaluable as identified needs have been addressed expeditiously. As a result of these communications, various guidelines have been written and provided theater wide. In particular, new resuscitation guidelines now establish parameters for the field and transport use of vasopressin, dobutamine, and norepinephrine for situations in which the burned multiple trauma patient may exhibit hypotension or decreased urine output despite adequate resuscitation and relative euvolemia (Tables 1 and 2). AQ:1, T1-2

An example of the effectiveness of this performance improvement process is the significant decline in the rate of ACS from large-volume resuscitations. Before the implementation of these guidelines, 13% of soldiers with TBSA burns greater than20% underwent decompressive laparotomies for ACS in theater.[25] Since the implementation this standard for burn shock resuscitation, (Tables 1 and 2) there have been no further cases of decompressive laparotomies secondary to large-volume resuscitation.

Burn Flow Sheet

To ensure proper documentation of care, a burn flow sheet was developed and disseminated for use during evacuation (Figure 1). The flow sheet has been a valu- F1, AQ:2

Table 1. Recommendations for the difficult fluid resuscitation

At 12 to 18 hours after burn injury, calculate the PROJECTED 24-hour resuscitation if fluid rates are kept constant. If the projected 24-hour resuscitation requirement exceeds 6 ml/kg/%TBSA, then the following steps are recommended.

1. Initiate 5% albumin early as described previously in the *Emergency War Surgery Handbook*.
2. Check bladder pressures every 4 hours.
3. If urine output (UOP) <30 ml/hr, strongly consider the placement of a pulmonary artery (PA) catheter to guide resuscitation with specific pulmonary capillary wedge pressure (PCWP) and mixed venous saturation (SvO_2) goals. (Goal PCWP 10–12, SvO_2 65–70%). If PA catheter placement is not practical then consider monitoring central venous pressures (CVP) from a subclavian or IJ along with central venous ($ScvO_2$) saturations (goal CVP 8–10, $ScvO_2$ 60–65%).
   a. If CVP or PCWP not at goal then increase fluid rate.
   b. If CVP or PCWP at goal then consider vasopressin 0.04 Units/min to augment mean arterial prssure (and thus UOP) or dobutamine 5 μg/kg/min (titrate until SvO_2 or $ScvO_2$ at goal). Max dose of dobutamine is 20 μg/kg/min.
   c. If both CVP or PCWP and SvO_2 or $ScvO_2$ at goal, then stop increasing fluids (even if UOP <30 ml/hr). The patient should be considered hemodynamically optimized and the oliguria is likely a result of established renal insult. Some degree of renal failure should be tolerated and expected. Continued increases in fluid administration despite optimal hemodynamic parameters will only result in "resuscitation morbidity," that is oftentimes more detrimental than renal failure.
4. If the patient becomes hypotensive along with oliguria (UOP <30 ml/hr), then follow the hypotension guidelines.
5. Every attempt should be made in minimize fluid administration while maintaining organ perfusion. If UOP >50 ml/hr, then decrease the fluid rate by 20%.

After 24 hours, infusion using Lactated Ringer's should be titrated down to maintenance levels and albumin continued until the 48-hour mark.

Table 2. Hypotension guidelines

The optimal minimum blood pressure for burn patient must be individualized. Some patients will maintain adequate organ perfusion (and thus have adequate UOP) at mean arterial pressures (MAPs) lower than 70. True hypotension must be correlated with UOP. If a MAP (generally <55 mm Hg) is not adequate to maintain the UOP goal of at least 30 ml/hr, then the following steps are recommended:

1. Start with vasopressin 0.04 units/min drip (do not titrate)
2. Monitor central venous pressure (CVP; goal 8–10).
3. If CVP not at goal, then increase fluid rate.
4. If CVP at goal, then add Levophed (norepinephrine) 2–20 μg/min.
5. If additional pressors are needed, consider the placement of a pulmonary artery catheter to guide resuscitation with specific pulmonary capillary wedge pressure (PCWP) and mixed venous saturation (SVO_2) goals. (Goal PCWP 10–12, SVO_2 65–70%). These patients may be volume depleted but a missed injury should be suspected.
   a. If PCWP not at goal, then increase fluid rate.
   b. If PCWP at goal, then consider Dobutamine 5 μg/kg/min (titrate until SvO_2 at goal). Max dose of dobutamine is 20 μg/kg/min.
   c. If hypotension persists, look for missed injury.
   d. Consider adding epinephrine or neosynephrine as a last resort.
6. If the patient is exhibiting catecholamine-resistant shock, consider the following diagnoses:
   a. Missed injury and ongoing blood loss.
   b. Acidemia. If pH <7.20, then adjust ventilator settings to optimize ventilation (target PCO_2 30–35). If, despite optimal ventilation, patient is still has a pH <7.2, consider bicarb administration.
   c. Adrenal insufficiency. Check a random cortisol and add start hydrocortisone 100 mg every 8 hours.
   d. Hypocalcemia. Maintain ionized calcium >1.1.

able documentation tool to record the first 72 hours of resuscitation as the patient moves through the various echelons of care. At each level of evacuation, this flow sheet ensures the appropriate repeated assessment of the resuscitation which is vital in all difficult resuscitations. On arrival to our burn center, this flow sheet enables our providers with necessary data to evaluate the patient's initial resuscitation course. This resuscitation tool has been vital in providing continuity in documentation as well as system-wide standardization of care.

FUTURE DIRECTIONS

The immediate efforts to avoid the consequences of both under- and over-resuscitation of the combat burned patient has included the standardization of initial burn care, a method of accurate reliable documentation, and an avenue for constructive feedback. The development of standardized protocols based on the best available clinical knowledge helps improve care in various clinical settings. Going further to incorporate these protocols into interactive computerized applications may prove to be the 'next generation' of advancement in burn resuscitation.[26] This type of application will enhance our ability to standardize the burn resuscitation system wide and project burn expertise to providers at every level. Au-

JTTS Burn Resuscitation Flow Sheet **Page 3**

Date:

Name	SSN	Pre-burn Est. Wt (kg)	%TBSA	Fluid Volume ACTUALLY received 1st 24 hrs	2nd 24 hrs	48 hr Total

Date & Time of Inury

BAMC/ISR Burn Team DSN 312-429-2876

Tx Site/ Team	HR from burn	Local Time	Crystalloid / (ml) / Colloid	TOTAL	UOP	Base Deficit	BP	MAP (>55) / CVP	Pressors (Vasopressin 0.04 u/min)
	49th								
	50th								
	51st								
	52nd								
	53rd								
	54th								
	55th								
	56th								
	57th								
	58th								
	59th								
	60th								
	61st								
	62nd								
	63rd								
	64th								
	65th								
	66th								
	67th								
	68th								
	69th								
	70th								
	71st								
	72nd								
	Total Fluids (72hrs):								

Figure 1.●●●

tomated "decision support" algorithms presently are under development at the ISR.

Small studies have demonstrated great potential in limiting the amount of fluid required for resuscitation by using plasma, hypertonic saline, and high-dose vitamin C during the initial burn resuscitation.[27–29] These adjuncts, which have been found to decrease "resuscitation morbidity," also may prove to be logistically useful as our military continues operations far-forward in austere environments. Hetastarch as a resuscitation adjunct, although theoretically ideal, has never been completely studied in patients with burns. Products like these that help limit total fluid requirements, while providing optimal end-organ perfusion, especially early in the resuscitation may prove to be invaluable.

CONCLUSIONS

Optimal burn resuscitation requires the close scrutiny of an experienced burn provider to minimize complication of both over- and under-resuscitation. Constant reassessment of composite endpoints to guide the resuscitation is a must. Even under perfect circumstances, the "textbook" resuscitation is a rare occurrence. Adding an evacuation out of an austere environment to a CSH, then air evacuation across three continents with care delivered by multiple teams of providers along the way, significantly increases the degree of difficulty in achieving an optimal resuscitation. System-wide solutions to identified problems now have been implemented, illustrating our ability

to evolve as a medical system. Ensuring institutional memory of already-applied solutions and enhancing our ability to perpetually evolve have become our next challenges.

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